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Synthesis, Characterization and Testing of Black Metal Oxide Nanoparticles as Solar Concentrator Receiver Material

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Abstract

Concentrator Solar Power (CSP) technologies use mirrors to concentrate the Sun's light energy on a small area called receiver. This technology is gaining interest of many researchers due to its high potential to generate power best during the late afternoon hours and to potentially displace the use of fossil fuel plants that emit the greenhouse gases that cause climate change. One of the crucial challenges of CSP technology is lack of a high-performance solar absorbing material at high temperature. Therefore, the present work is focused to synthesize cobalt oxide nanoparticles and testing of these particles as solar concentrator receiver. These particles are synthesized by sol-gel method with varying concentration of precursors. Further, the surface morphology of these particles are analyzed using Scanning Electron Microscopy (SEM). The crystal structure of cobalt oxide is confirmed by X-ray diffraction studies. To study the optical properties of prepared samples, FTIR and UV-Visible-NIR spectroscopies have also been done. Synthesized black oxide Co_3O_4 nanoparticles are dispersed in locally available solar absorber materials and different samples are prepared. The composite of cobalt oxide nanoparticles and black matt paint are characterized by UV-Vis-NIR spectroscopy. The mixing of cobalt oxide nanoparticles in solar absorber paint increases the absorbing capacity of the paint.

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Keywords: Concentrating solar power; solar absorber; nanoparticles; sol-gel method.

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1. Introduction

The expeditious depletion of non-renewable sources of energy at alarming rate draws the awareness towards the development and deployment of inexhaustible energy sources[1–3]. Concentrator Solar Power technologies and Photovoltaic technologies are the preferred alternatives to reduce reliance on fossil fuels and for lowering emission of greenhouse gases. According to some experts it is assumed that by 2030 fossil fuels will face price competition with solar technologies[4]. Solar energy can be converted into electricity directly through photovoltaic technology or indirectly by means of Concentrator Solar Power (CSP) technology. Other than power generation CSP has major potential in high-temperature thermal applications.

CSP systems require innovation in two major areas i.e. 1) the reflector material, which can efficiently concentrate the solar radiation to the target and 2) the absorber material, which can absorb maximum concentrated radiation without significant radiative losses[5][6]. Solar absorber materials are very important aspect of CSP technology. The efficiency of a CSP system, not only depends on the solar convergence power of a concentrator but also depends on effectiveness of heat absorbed and transfer to the target. At this point, a need for efficient absorber material comes into existence[7].

Nanomaterials are now-a-days attracting the attention of researchers in almost every segment of innovations in technology. Since, the efficiency of the generation of solar energy is directly related to the extent of the absorption of light, a vast variety of investigations had been pursued for the enhancement of optical absorption. However, majority of these studies are done for the application of photovoltaic system and may not be applicable to the CSP applications, where light absorbing layers are generally employed using spray coating[8,9]. For solar absorber, metal oxide nanoparticles such as copper oxide and cobalt oxide nanoparticles (CONPs) either neat or in blended with other materials are widely used. Studies had also been done on copper-cobalt oxide composite thin films and promising results were shown for selective solar absorber application[10]. Many researchers prefer cobalt oxide over copper oxide due to their easy synthesis and stability at higher temperature[11]. For instance CoO and Co₃O₄ are the two forms of cobalt oxides which are stable above 500⁰ C[12–14]. Cobalt oxide nanoparticles are strong candidate for electronic devices, gas sensing, electrochromic devices, magnetic materials, energy storage batteries, solar absorbers at high temperature, etc[15–20].

Considering above, present work is focused on fabrication of an efficient and stable receiver material for the high-temperature CSP system with low cost. Several studies have been reported optical absorption enhancement using the selective coating in solar absorbers. Light absorbing coatings based on cobalt oxide nanoparticles for concentrator receiver has also been studied using different methods. Yet synthesis of nanoparticles at low cost, preparing a material which is easily spread or coated on a receiver and can stand at high temperature without degradation are still challenging aspects.

This paper presents a comparison between cobalt oxide nanoparticles of different sizes and its composite with matt black paint for solar absorbance. The major problem with the conventional paints is that, they cannot withstand high temperatures generated in CSP systems and peel off with time. Also, their solar absorbing capacity is not excellent and needs to be upgraded[7]. To address these problems, cobalt oxide nanoparticles are synthesized in different sizes and their composite with locally available paint are made in different proportions to get the optimized results. The mixing of cobalt oxide nanoparticles in solar absorber paint not only increase the absorbing capacity of the paint but also enhance its adhesion to the metallic surface[21].

2. Experimental Studies

2.1 Cobalt oxide nanoparticle synthesis

We aimed to synthesize nanoparticles having size in the range of few hundred nanometer because very small particles are not very good candidate for the purpose of light trapping[21,22]. The synthesis of cobalt oxide nanoparticles was done by co-precipitation method as described by Katalin Sinkó et. al[23]. Cobalt nitrate hexahydrate was used as precursor and oxalic acid was used as precipitating agent. No capping agent was used in this synthesis. The aqueous solutions of cobalt nitrate and oxalic acid were prepared in the concentrations of 0.25M, 0.5M and 1.0M in 100 mL de-ionized water and are named as sample 1, sample 2 and sample 3 respectively for convenience. Then oxalic acid was added drop wise into the cobalt nitrate solution under constant and vigorous

stirring at room temperature. The resulting solution was allowed to stir for 2 hours at room temperature. The pink precipitate of cobalt oxide was then washed using de-ionized water using centrifuge until the pH of the supernatant becomes neutral. Finally, the pink precipitate was dried in oven at 100°C for 24 hours. The dark pink cobalt oxide nano particles were then heated to 250°C degrees for phase stabilization. Black colored cobalt oxide nano particles were then recovered.

2.2 Fabrication of Co_3O_4 composite with black matt paint

Asian matt blackpaint was used for experiments[24]. This paint was diluted from turpentine as applicable. The black matt paint and cobalt oxide Nano composite (sample 3) was prepared using bath ultra-sonicator in the ratio of 1:1 and 3:1 respectively. In this step, the 1:1 and 1:3 mixture were separately sonicated at room temperature for 2 hours. The resultant mixture was dried at 150°C in hot air oven for 12 hours. The final dried sample was removed from the glassware and crushed until a uniform powder was obtained. This dried powder was used in further characterisations.

3. Results and Discussions

X-Ray diffraction studies have been done on the samples using X'Pert3 Powder PAN Analytical Instrument. The diffraction graph for sample 1, sample 2 and sample 3 are shown in figure 1. It confirms that the synthesized compound is Co_3O_4 [21,25]. The peaks arising at 19° , 31° , 37° , 38.7° , 45° , 55.8° , 59.6° and 65.4° are due to the phases (111), (220), (311), (222), (400), (422), (511) and (440) respectively indicates the cubic spinel structure of Co_3O_4 . The XRD data confirms that the synthesized compound was Co_3O_4 .

EVO-18 Carl Zeiss Scanning Electron Microscope (SEM) is utilized for the study of surface morphology of the synthesized nanomaterial. SEM images are shown in the figure 2(a), (b), (c) and (d). The cobalt oxide Nanomaterials synthesized are spindle in shape (Figure 2(a)) and a relative increment of size is observed on increasing the concentration of the precursors.

FT-IR absorption spectrum of cobalt oxide was analysed using Shimadzu IR Affinity-1 Fourier transform infrared spectroscopy (FTIR) facility, in the range $4000\text{--}500\text{ cm}^{-1}$. This is shown in the figure 3. The FT-IR spectra revealed the characteristic absorption peaks for metal–oxygen bonding and oxygen–hydrogen bonding. The two very intense peaks around ν_1 (566 cm^{-1}) and ν_2 (665 cm^{-1}) are originating from the stretching vibrations of the cobalt–oxygen bond, characteristic of OB_3 (where $\text{B} = \text{Co}^{3+}$ at octahedral site) and ABO ($\text{A} = \text{Co}^{2+}$ in the tetrahedral site) in the spinel cobalt oxide. The absorption peaks around ν_3 (1623 cm^{-1}) and ν_4 (3437 cm^{-1}) are assigned to the bending vibration of molecular water and OH-Stretching vibration, respectively[26–28].

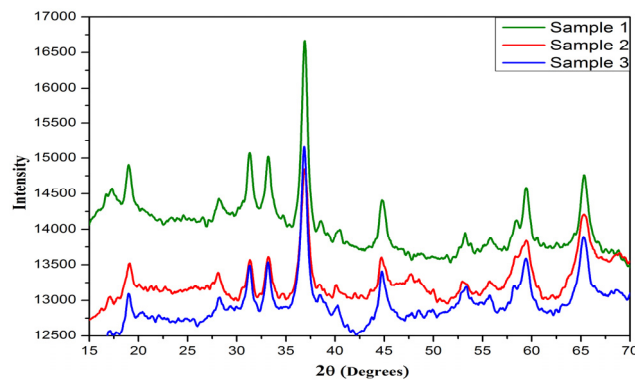


Figure 1. XRD data plot of Sample 1, 2 and 3

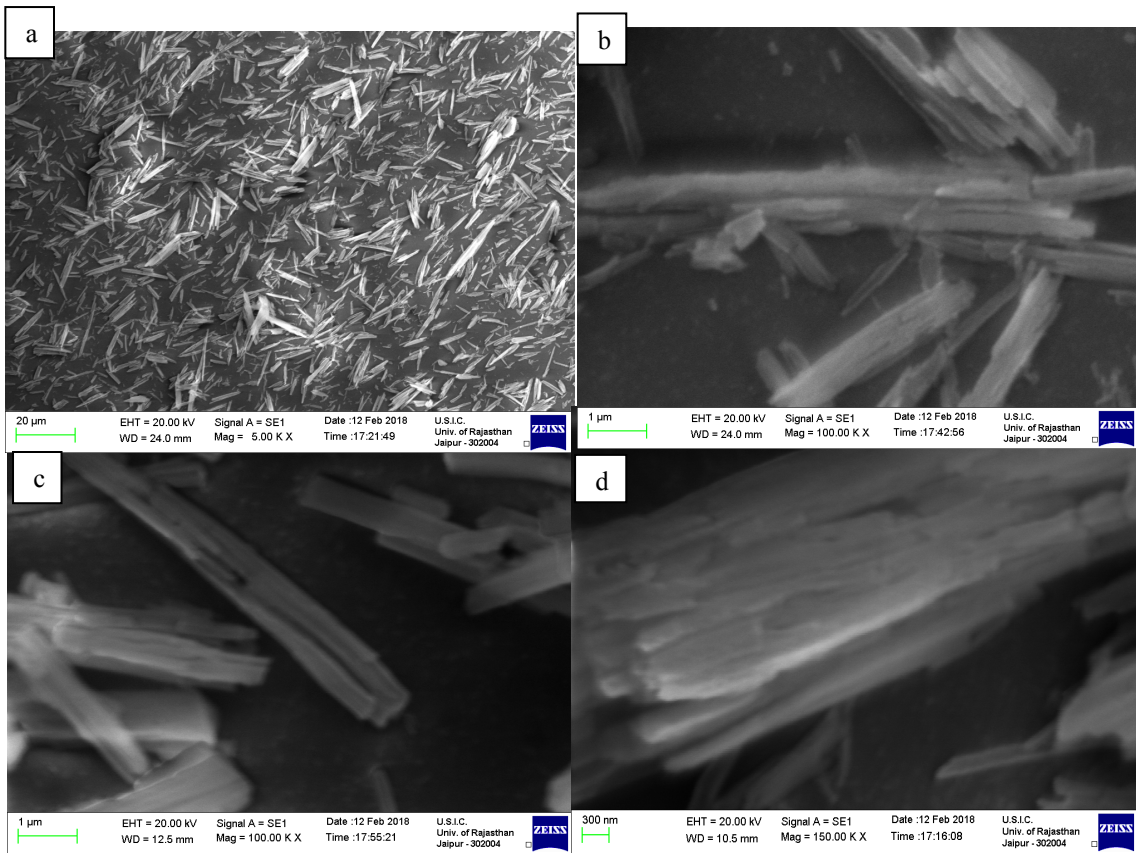


Figure 2(a). SEM image of Sample 1 at 5K magnification showing spindle shape morphology of the fabricated cobalt oxide nanomaterial, (b). SEM image of Sample 1, (c). SEM image of Sample 2, (d). SEM image of Sample 3.

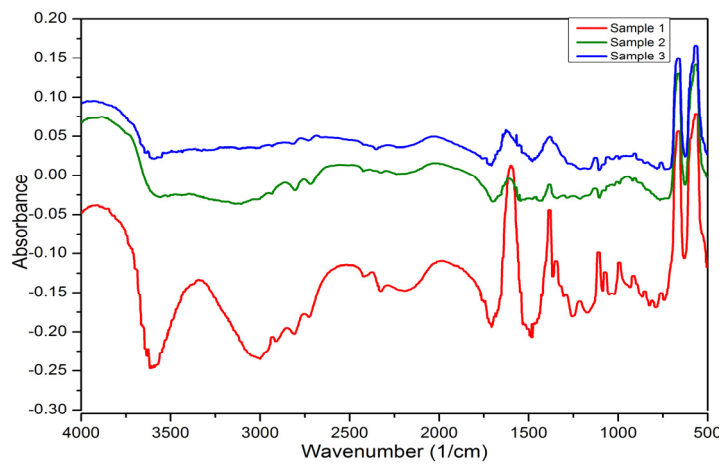


Figure 3. FT-IR data plot of Sample 1, 2 and 3.

UV-Vis-NIR graph of absorption is shown in figure 4(a); it shows high absorption bands from 250 to 700 nm (due to Co^{3+} component of Co_3O_4 [29]) and in 1300 to 1600 nm it reveals that the synthesized samples are very good absorbers in UV-Vis and near infrared region. This property of cobalt oxide nanoparticles makes it more suitable for

their application as solar absorber paints. UV-Vis-NIR graph of transmission is shown in figure 4(b) which shows the minimum transmission of light from the sample 3. Due to these desirable properties, sample 3 was used for composite fabrication.

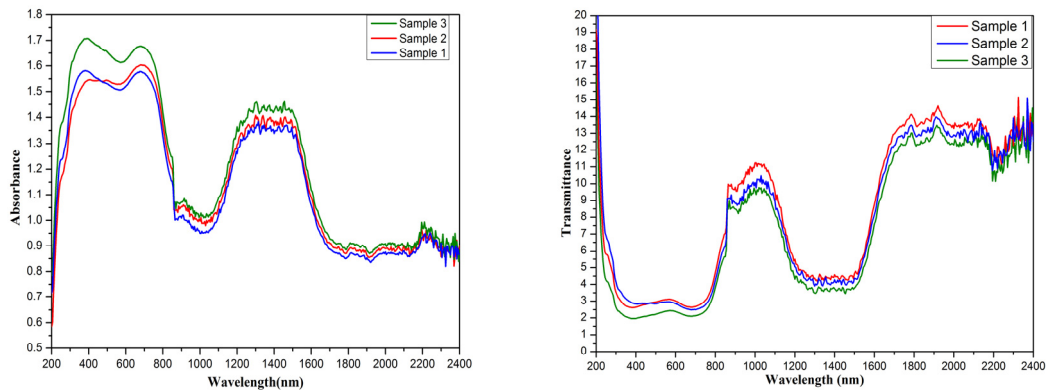


Figure 4(a). UV-Vis-NIR (absorption) data plot of Sample 1, 2 and 3.(b). UV-Vis-NIR (transmission) data plot of Sample 1, 2 and 3

The composite of cobalt oxide nanoparticles and black matt paint are characterized by UV-Vis-NIR spectroscopy. The results shown in figure 5(a) illustrates that the absorption spectrum of the paint is increased upon the addition of cobalt oxide nanoparticles and this effect increases on increasing the proportion of CONPs in the paint. As well as the transmittance spectra (figure 5(b)) also justifies that the 1:1 composite has lower tendencies for transmittance.

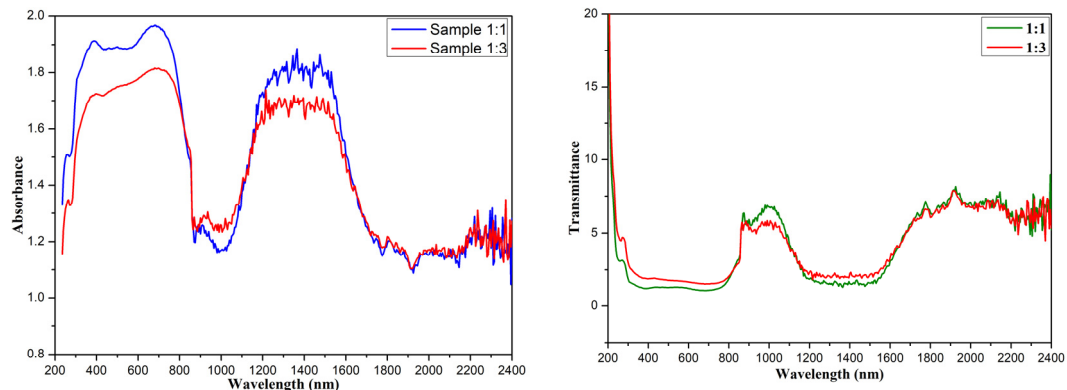


Figure 5(a)UV-Vis-NIR (absorption) data plot of Sample 1, 2 and 3.(b). UV-Vis-NIR (transmission) data plot of Sample 1, 2 and 3

Hence, the mixing of cobalt oxide nanoparticles in solar absorber paint increases the absorbing capacity of the paint. These results are in agreement with the reference [21]. Future scope of the work is testing of durability and absorption performance at feverish temperature of these composites.

4. Conclusion

In Summary, authors have fabricated cobalt oxide spindle shape nanoparticles using facile one pot synthesis using co-precipitation method. The composites of synthesized material with matt black paint, that is a commonly used solar absorber, increase the absorption of matt black paint. Present work has potential to extend this study for testing of these composite as high temperature solar absorber applications in Concentrator Solar Power (CSP) technologies.

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